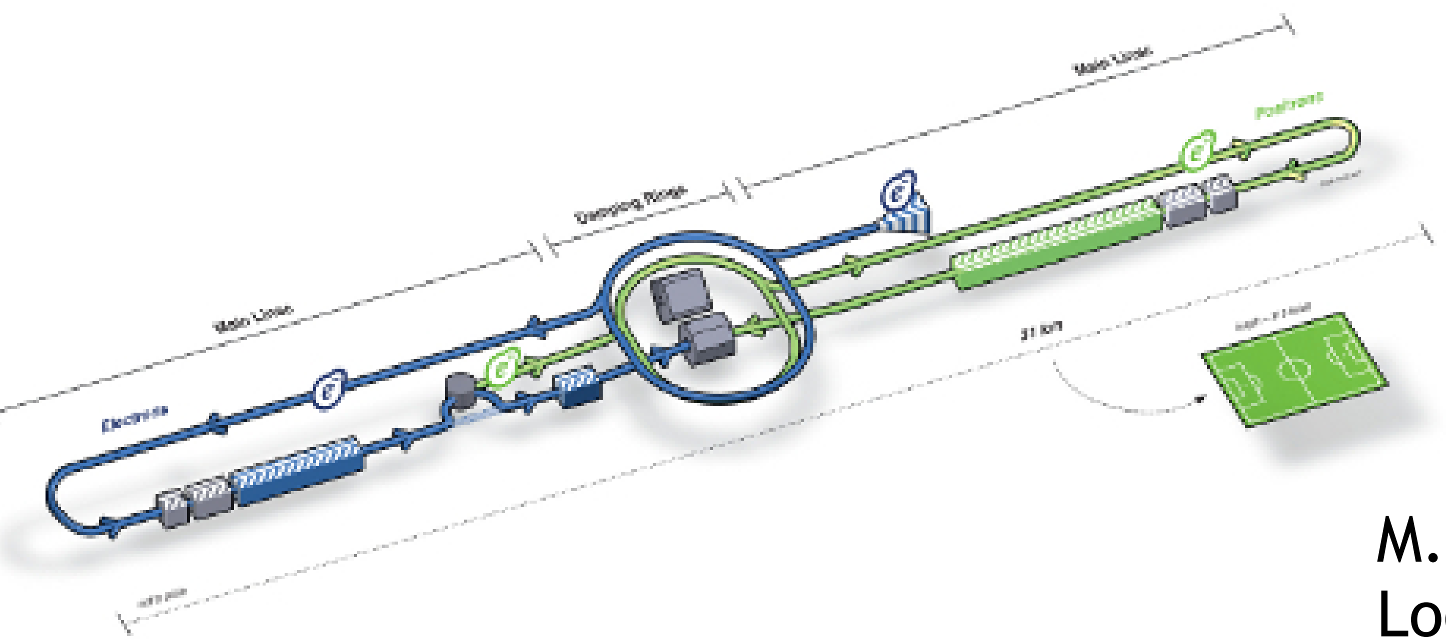
ILC
What is it?
What Must be Done?
Why Now?



M. E. Peskin, SLAC
Loopfest IX, June 2010

The original goal of the Loopfests was to encourage precision calculation for the needs of a future e+e- collider.

At this Loopfest, most of the talks deal with issues at hadron colliders. This is natural, because QCD is difficult, and much more progress is needed for the interpretation of the LHC data.

At the same time, e+e- colliders should not slip off the map.

So,

What is this 'ILC' ?

What should theorists know about it ?

What does it need?

What is the ILC ?   There are three answers:

1. It is the e+e- collider that complements the LHC in a comparable energy region. As such, it is the natural next project in accelerator-based high-energy physics.

2. It is the accelerator that addresses the most important questions that will be left by the LHC:

within the Standard Model, to study the HIggs boson with high precision

beyond the Standard Model, to definitively characterize new particles

3. It is the major global project in high-energy physics, overseen by inter-regional organizations.

The ILC is the result of a broad international consensus on the next major project in high-energy physics, beginning with high-level regional committees in the US, Europe, and Japan in 2001.

In January 2004, the OECD Committee for Scientific and Technology Policy at Ministerial Level announced

"The Ministers ... commended the clarity and worldwide consensus they found among the high-energy physics community in developing a roadmap for future large accelerator-based facilities."

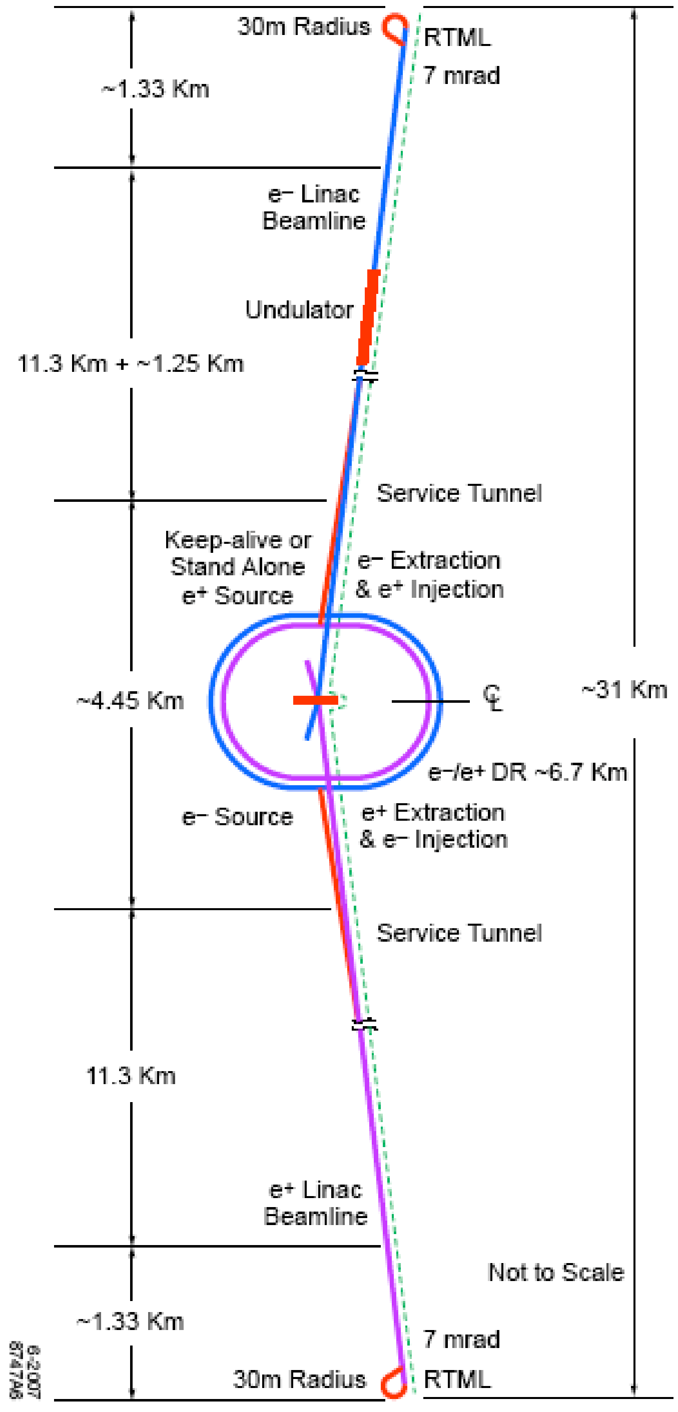
This roadmap includes as the "next major facility"
"a next generation electron-positron collider with a significant period of concurrent running with the LHC."

In answer to this charge, a global organization called the GDE was set up in 2005. This organization, headed by Barry Barish, issued a Reference Design Report in 2007. The design continues to evolve toward a full engineering proposal, expected in 2012.

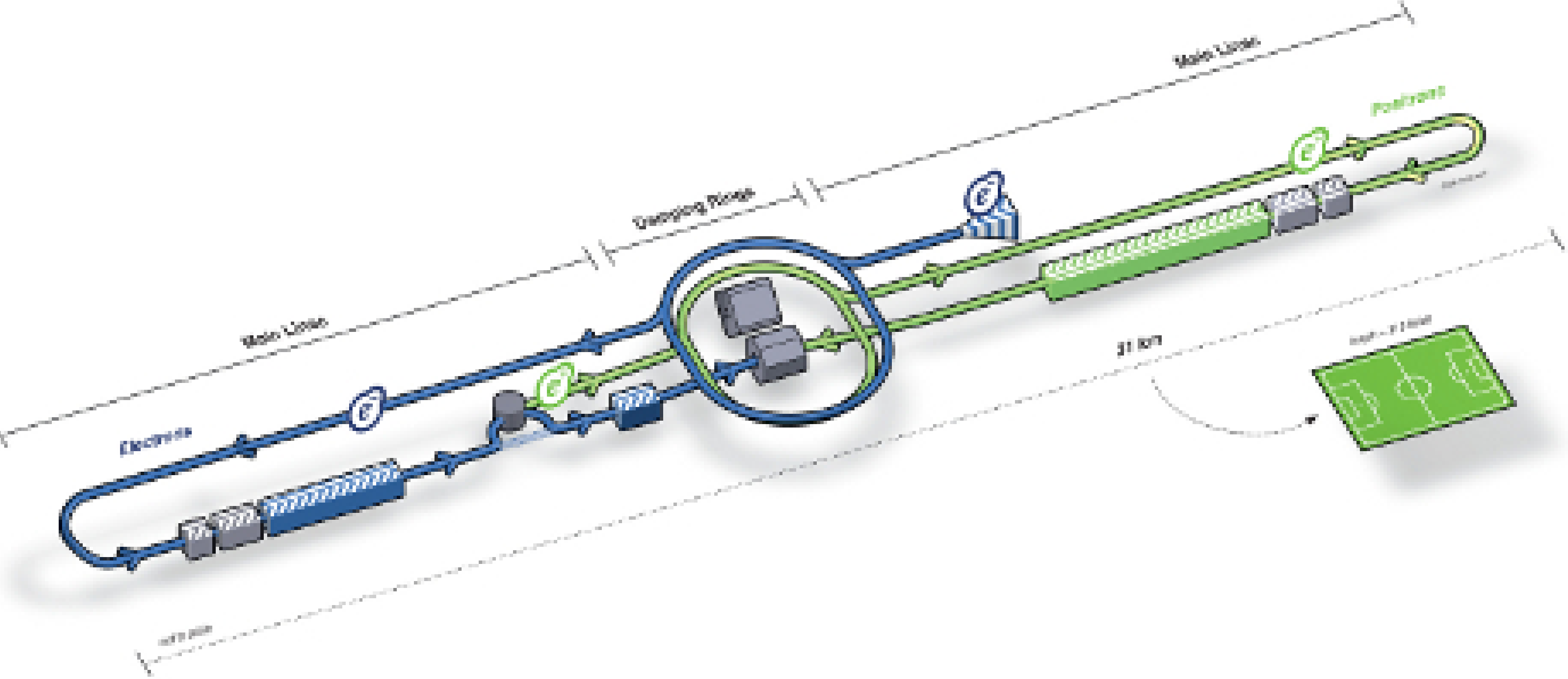
Here are some snapshots from the RDR:

maximum energy:	500 GeV	e+e- collisions
luminosity:	2×10^{34}	/cm2/sec
total length:	31 km	
cost:	6.62 B	(2007 US $)
	(materials cost excluding labor)	

ILC
site plan

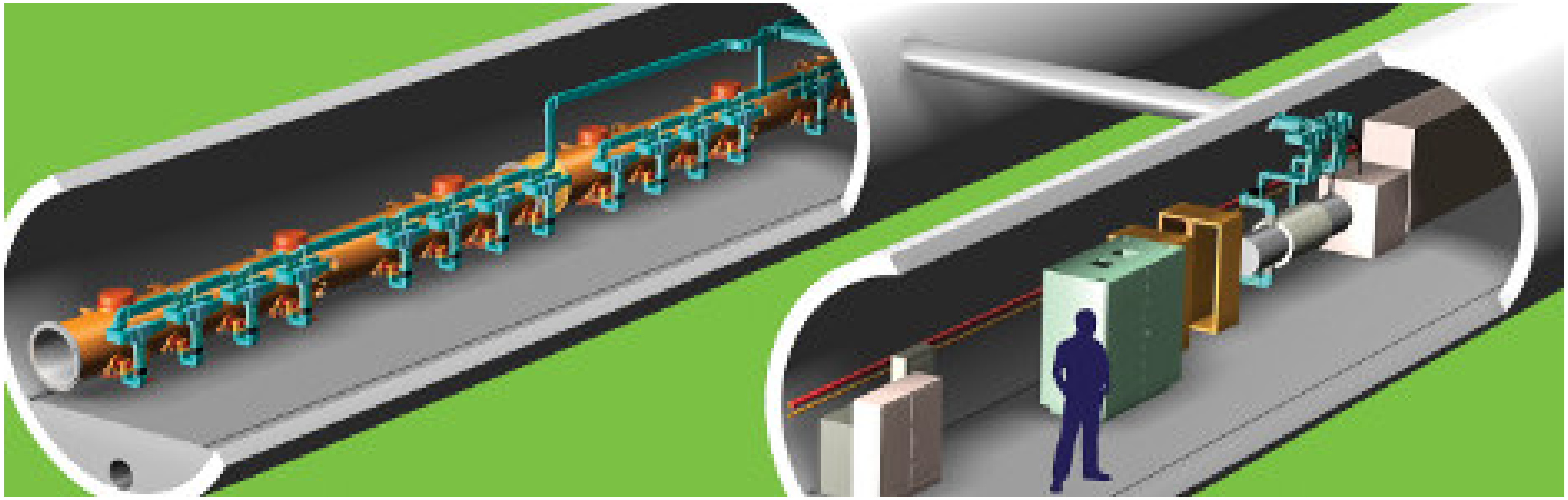


2007 ILC RDR

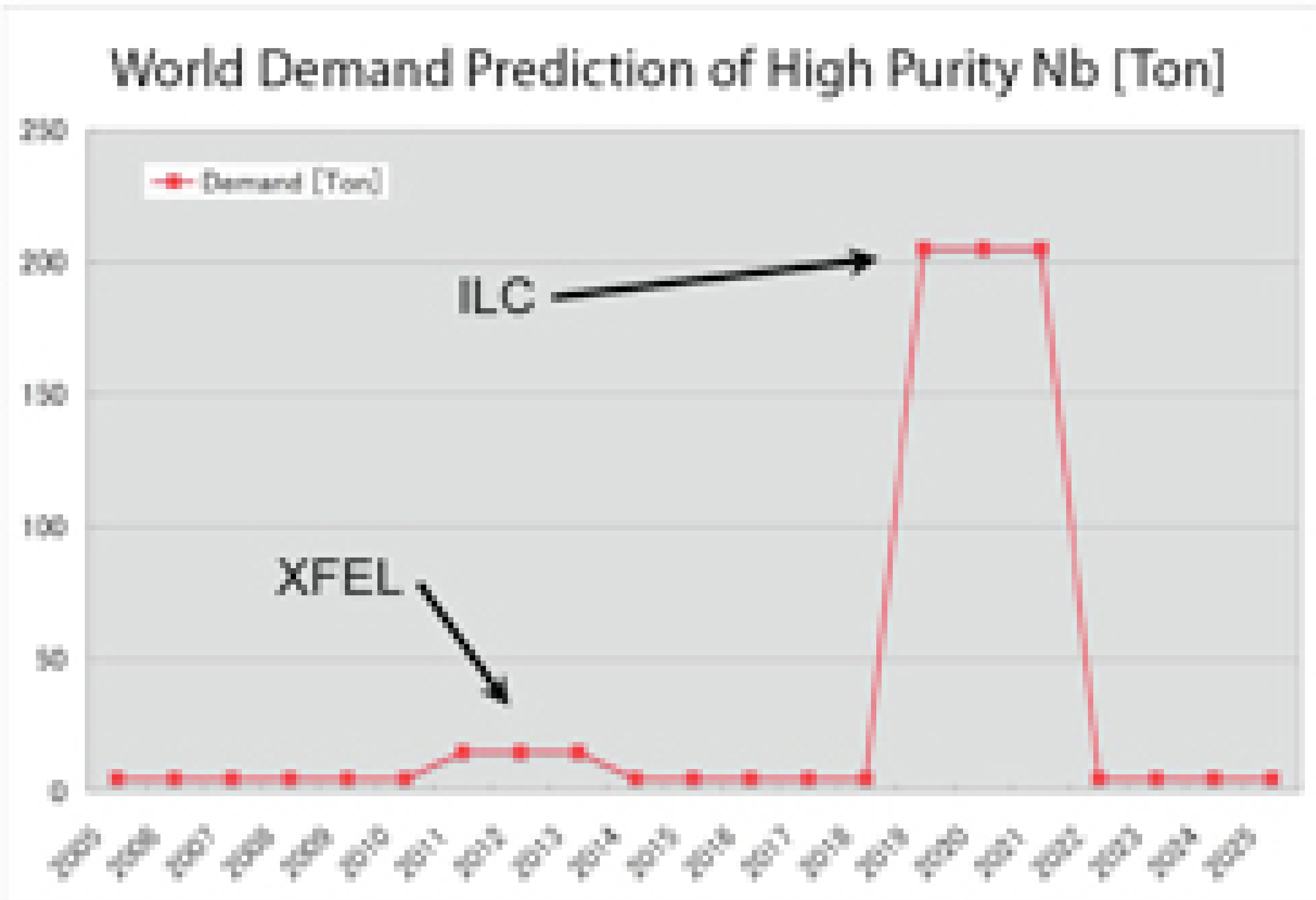


Main Linac
Damping Rings
Main Linac
Positrons
Electrons
31 km

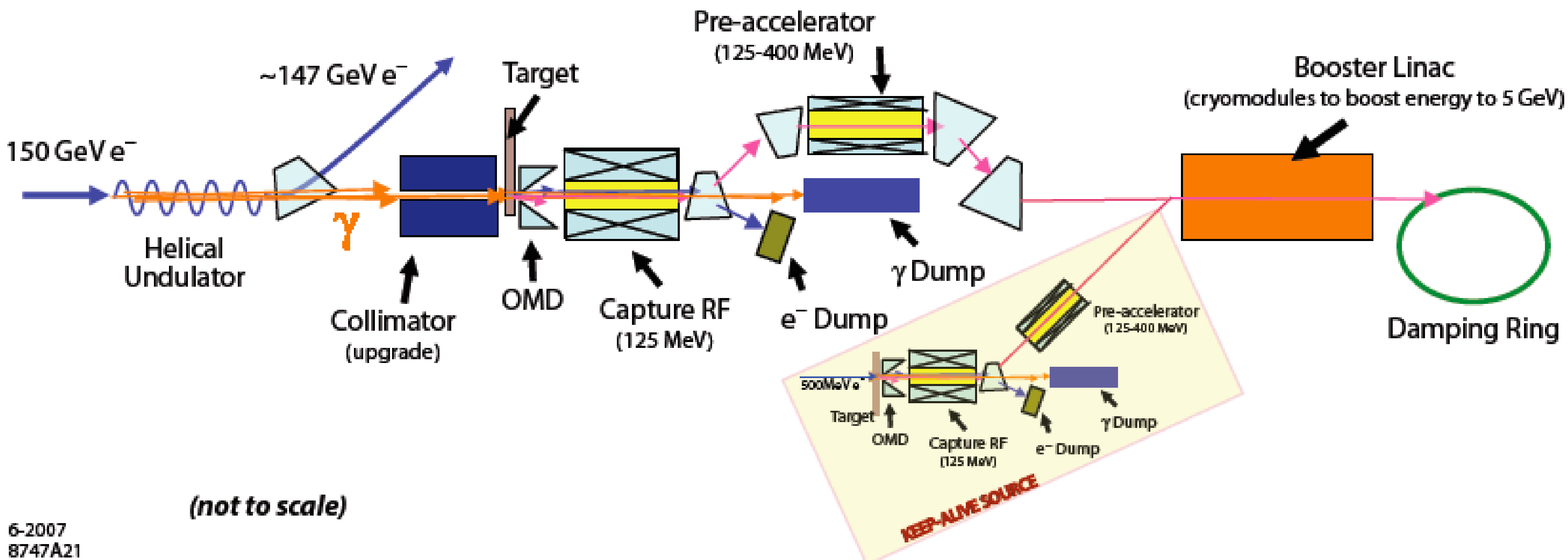
main linac: niobium superconducting cavities
31 MeV/m



ILC RDR


World Demand Prediction of High Purity Nb [Ton]
250
200
150
100
50
0
Demand [Ton]
ILC
XFEL

positron production by conversion of photons from a helical undulator



baseline: 80% electron polarization;
upgrade: + 60% positron polarization

What are the physics goals of the ILC ?

The ILC must answer the physics questions raised by the LHC.

Within the Standard Model, the LHC will discover the Higgs boson.

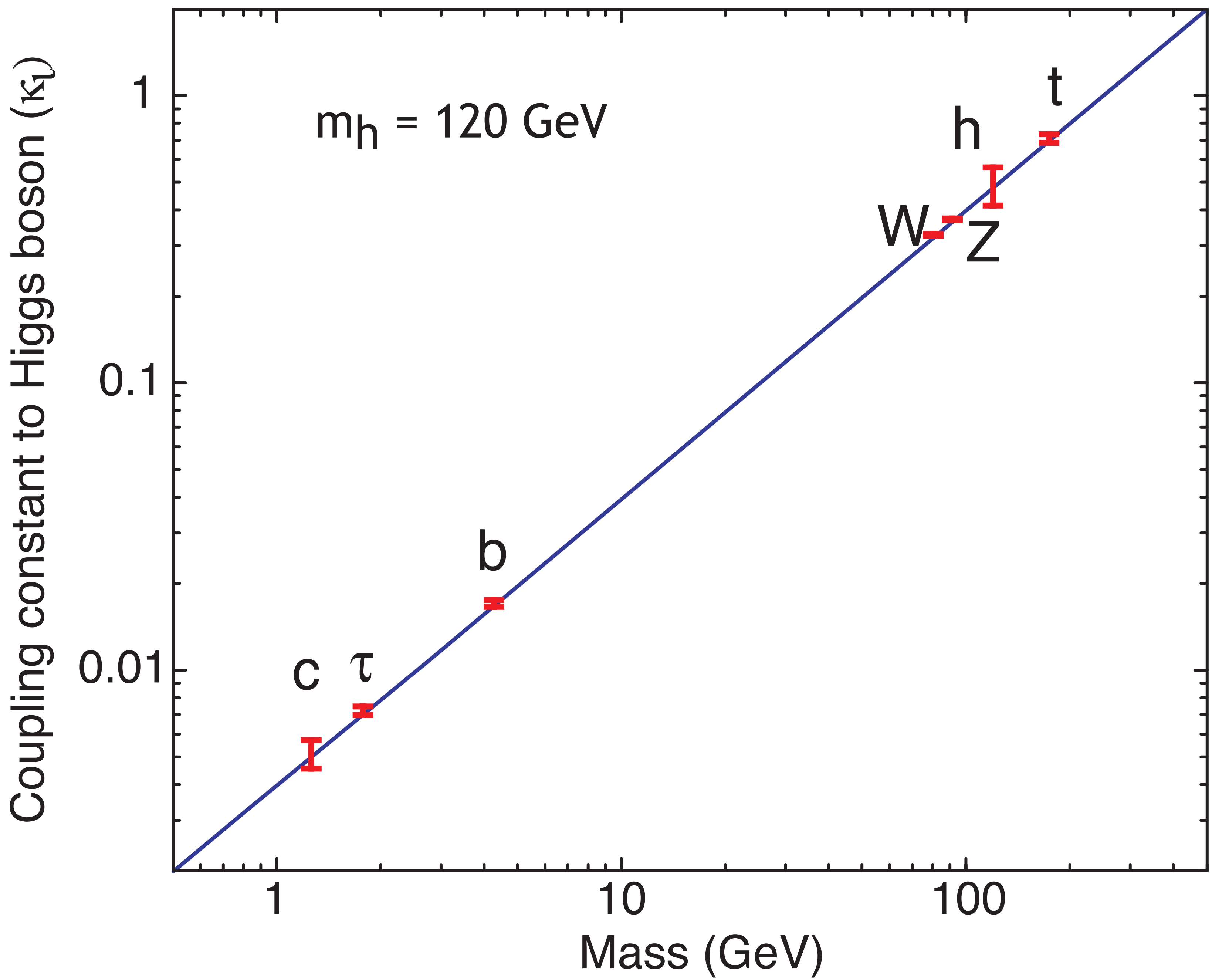
The ILC must observe all important decays of the Higgs boson and measure the Higgs couplings to high precision:

In the reaction $e^+e^- \to h^0 Z^0$ $\quad m_h = 120 \text{ GeV}:$

observe: $h^0 \to b\bar{b}, c\bar{c}, gg, \tau^+\tau^-, WW^*, ZZ^*, \gamma\gamma, \gamma Z$

with absolutely normalized branching ratios at % level of accuracy.

At 1 TeV, add the couplings $h^0 \to \mu^+\mu^-, t\bar{t}, h^0h^0$



ACFA LC study

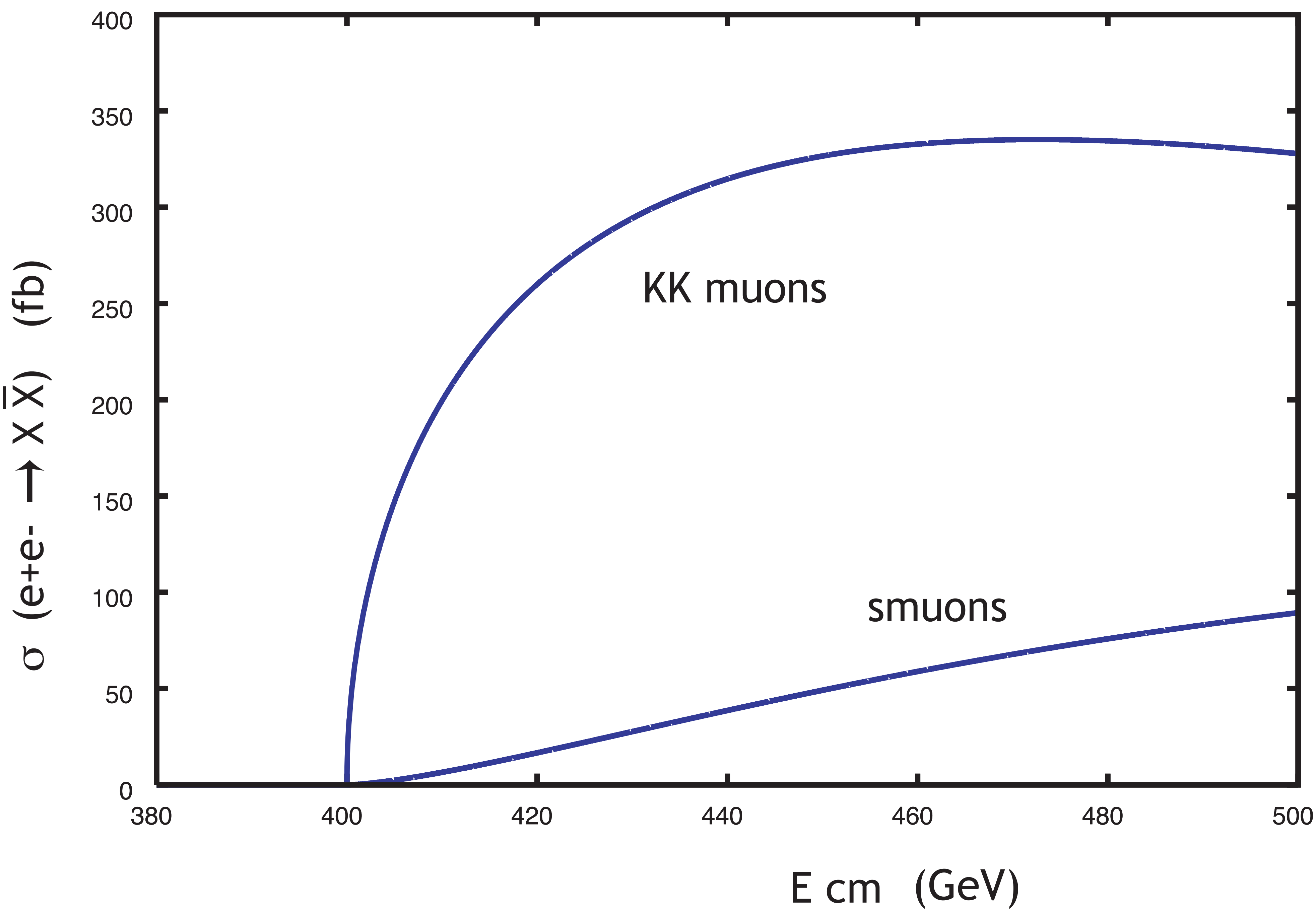
Beyond the Standard Model,

the LHC will discover new particles of supersymmetry or another new physics scenario. These might include the WIMP dark matter particle.

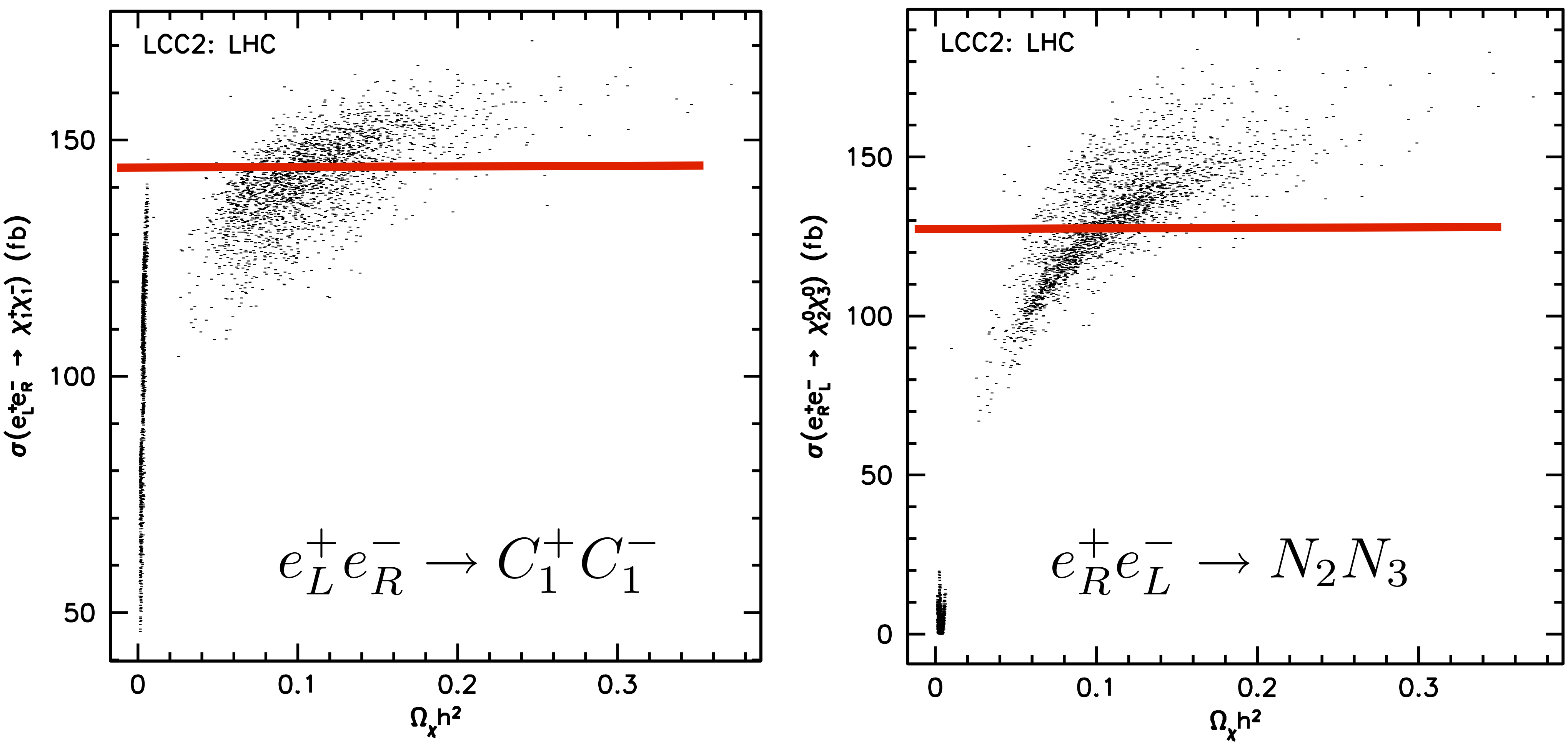
The ILC must characterize the new physics scenario uniquely, determining the spins and quantum numbers of a basic set of new particles.

The ILC must measure the couplings of a WIMP relevant to dark matter detection and annihilation cross section.

The ILC must measure properties of Higgs bosons and top/bottom partners relevant to electroweak symmetry breaking.

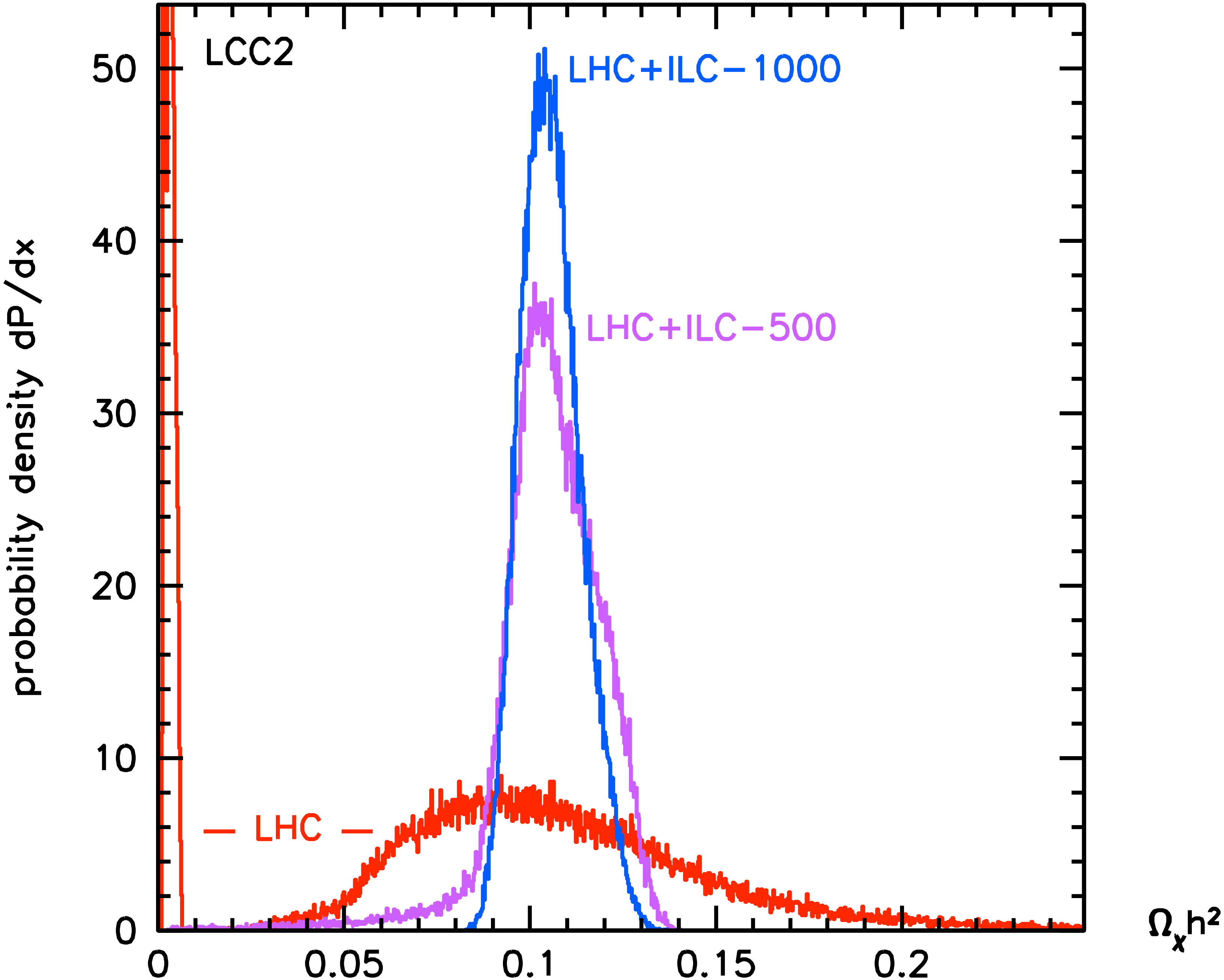


400
350
300
250
200
150
100
50
0
380
400
420
440
460
480
500
KK muons
smuons
σ (e+e- → X X̄) (fb)
E cm (GeV)

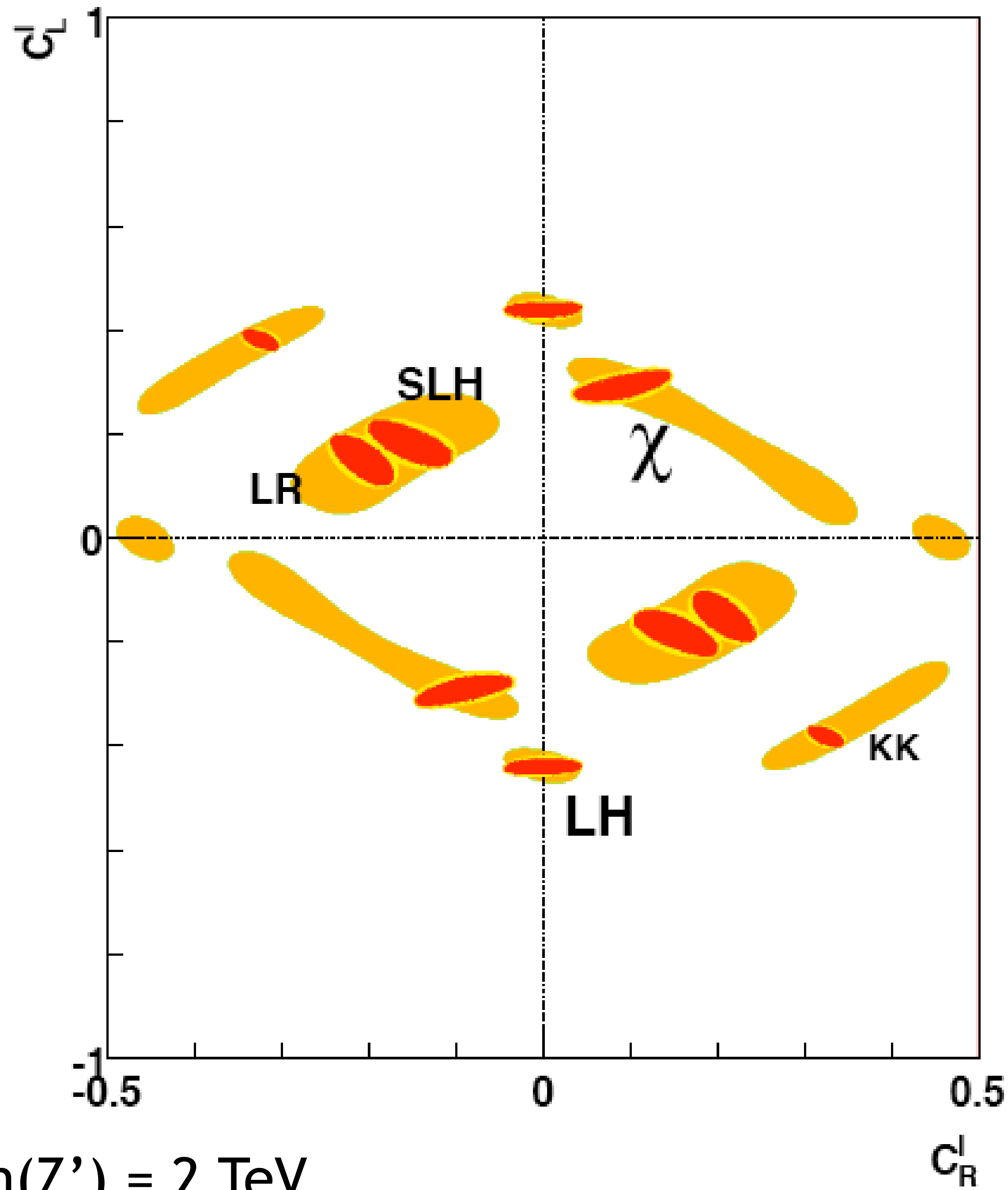


LCC2: LHC
$\sigma(e^+_L e^-_R \to \chi^+_1 \chi^-_1)$ (fb)
$\Omega_\chi h^2$
$e^+_L e^-_R \longrightarrow C^+_1 C^-_1$
LCC2: LHC
$\sigma(e^+_R e^-_L \to \chi^0_2 \chi^0_3)$ (fb)
$\Omega_\chi h^2$
$e^+_R e^-_L \longrightarrow N_2 N_3$

Baltz et al.


LCC2
LHC+ILC−1000
LHC+ILC−500
— LHC —
probability density dP/dx
$\Omega_\chi h^2$
0
10
20
30
40
50
0
0.05
0.1
0.15
0.2

Baltz et al.



500 GeV, m(Z') = 2 TeV
1 ab-1, $e^+e^- \rightarrow \mu^+\mu^-$

Godfrey, Kalyniak, Tomkins

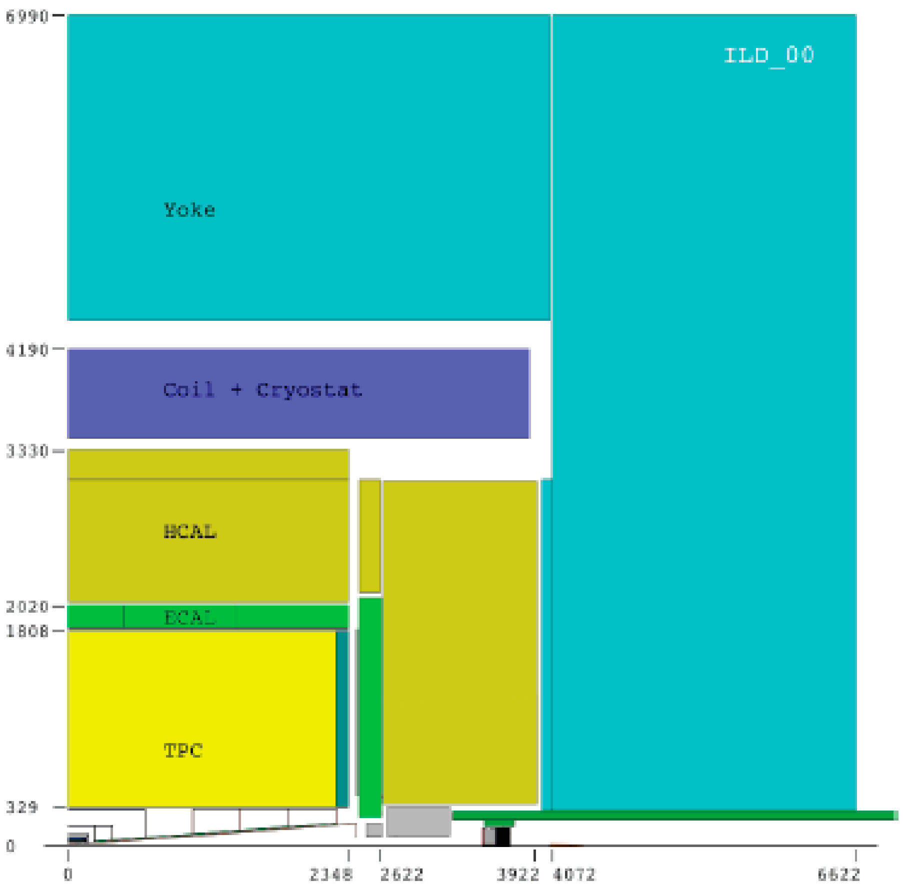
To address these physics questions, two global collaborations have designed detectors.

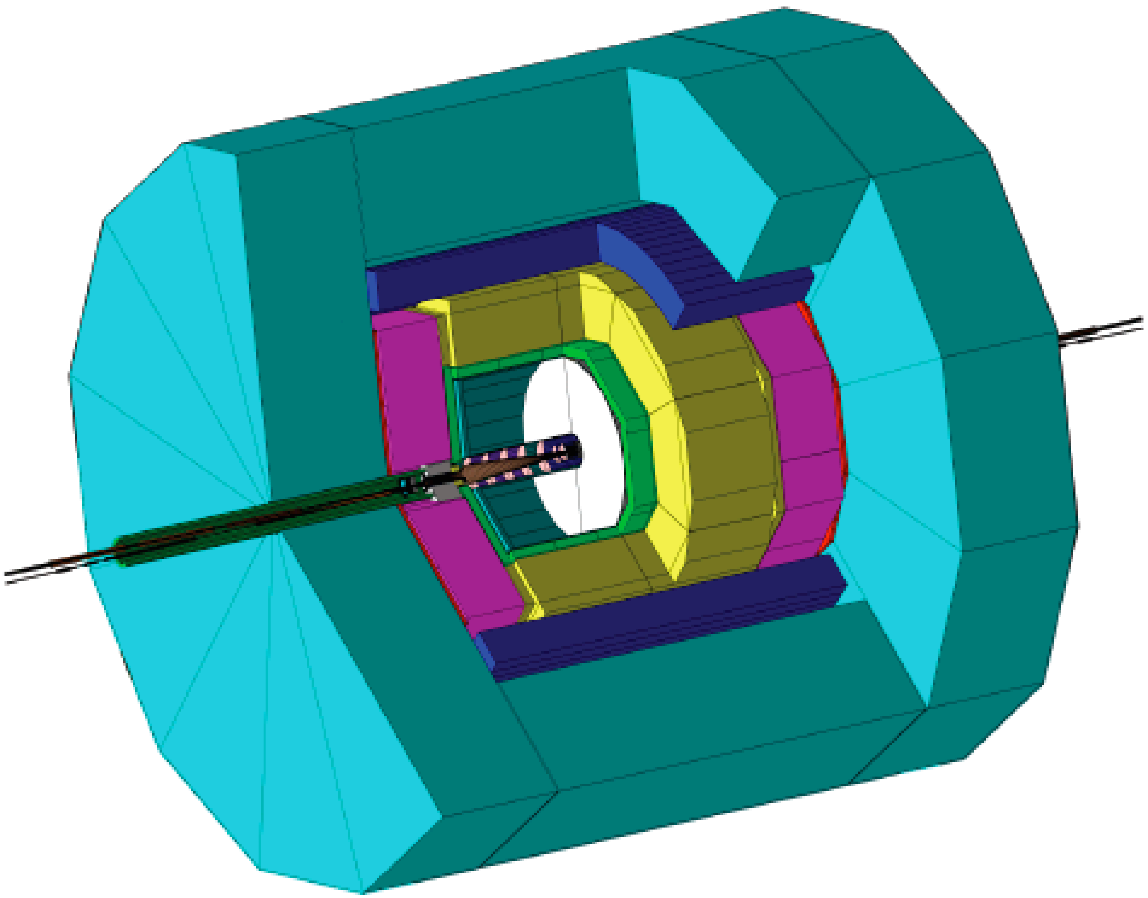
ILD - large detector built around a TPC

SiD - compact detector with all-silicon tracking

These collaborations issued Letters of Intent in 2009. These are 150-page documents including full-simulation physics analyses with realistic machine backgrounds.

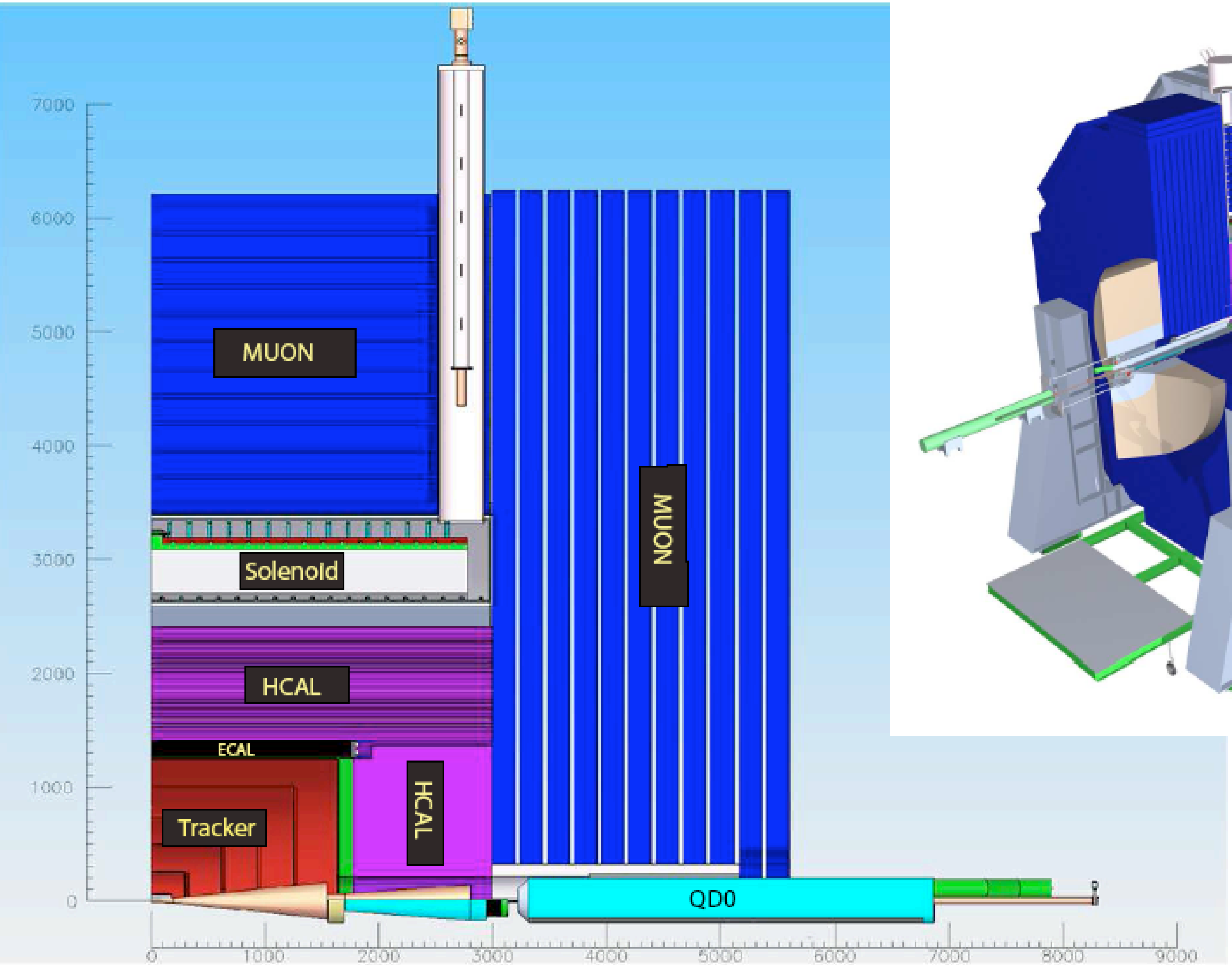
ILD detector

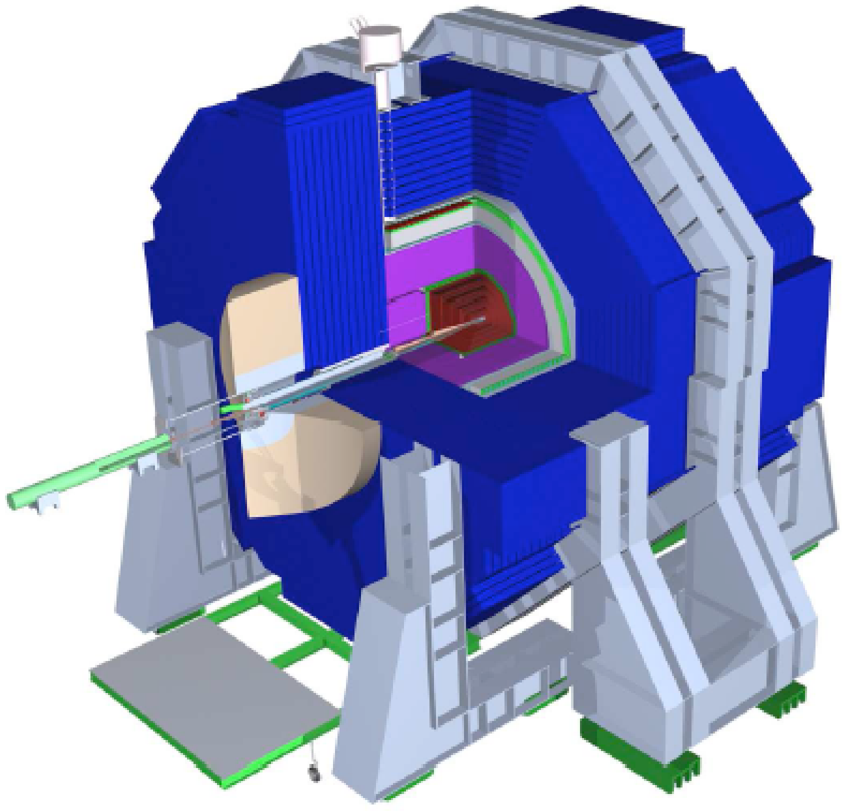




ILD LOI

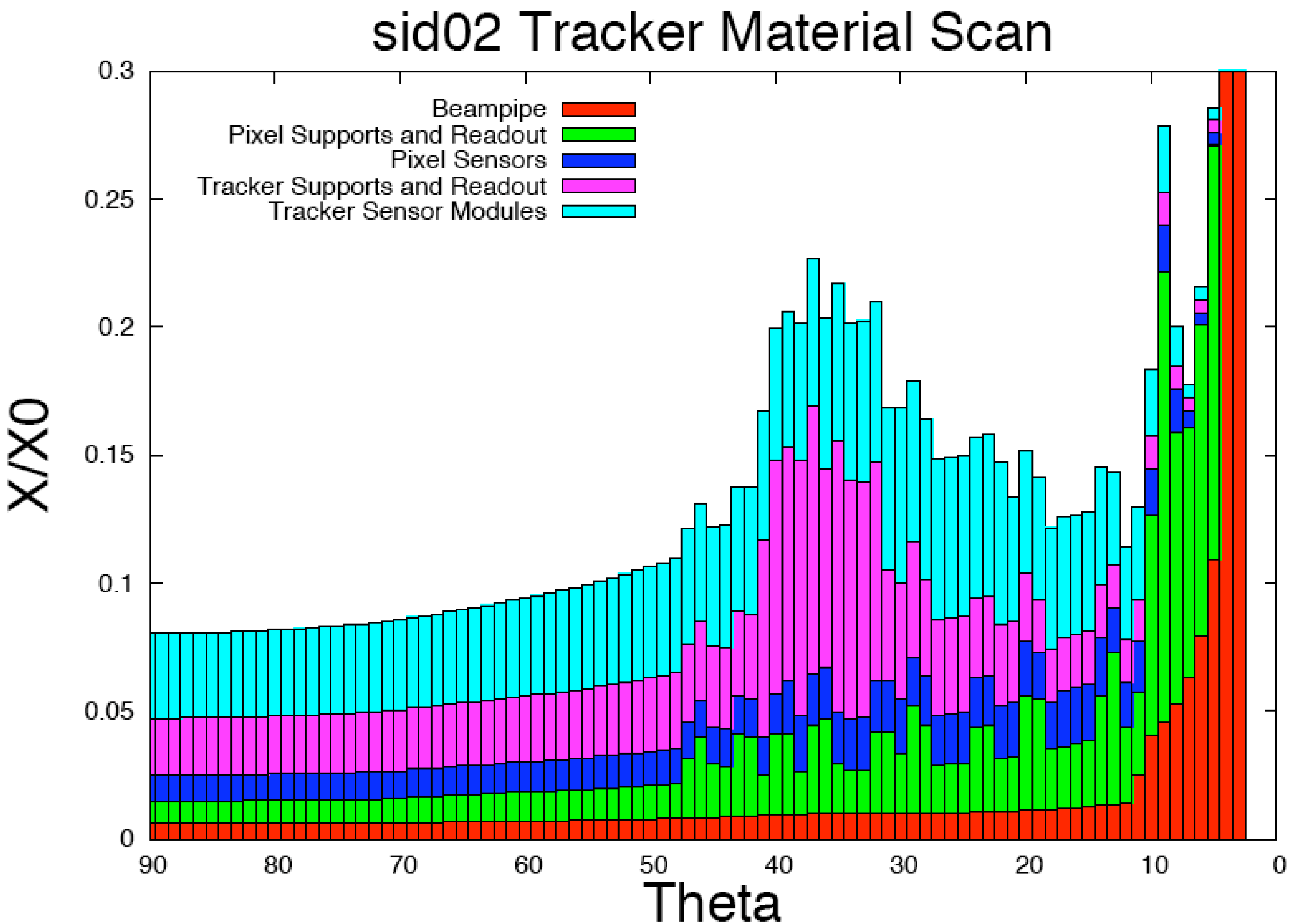
SiD detector





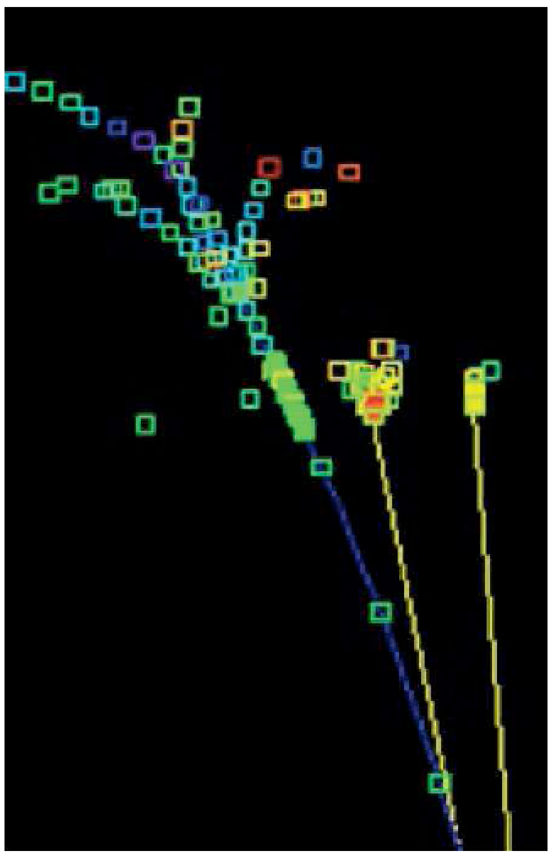
SiD LOI

SiD detector material budget



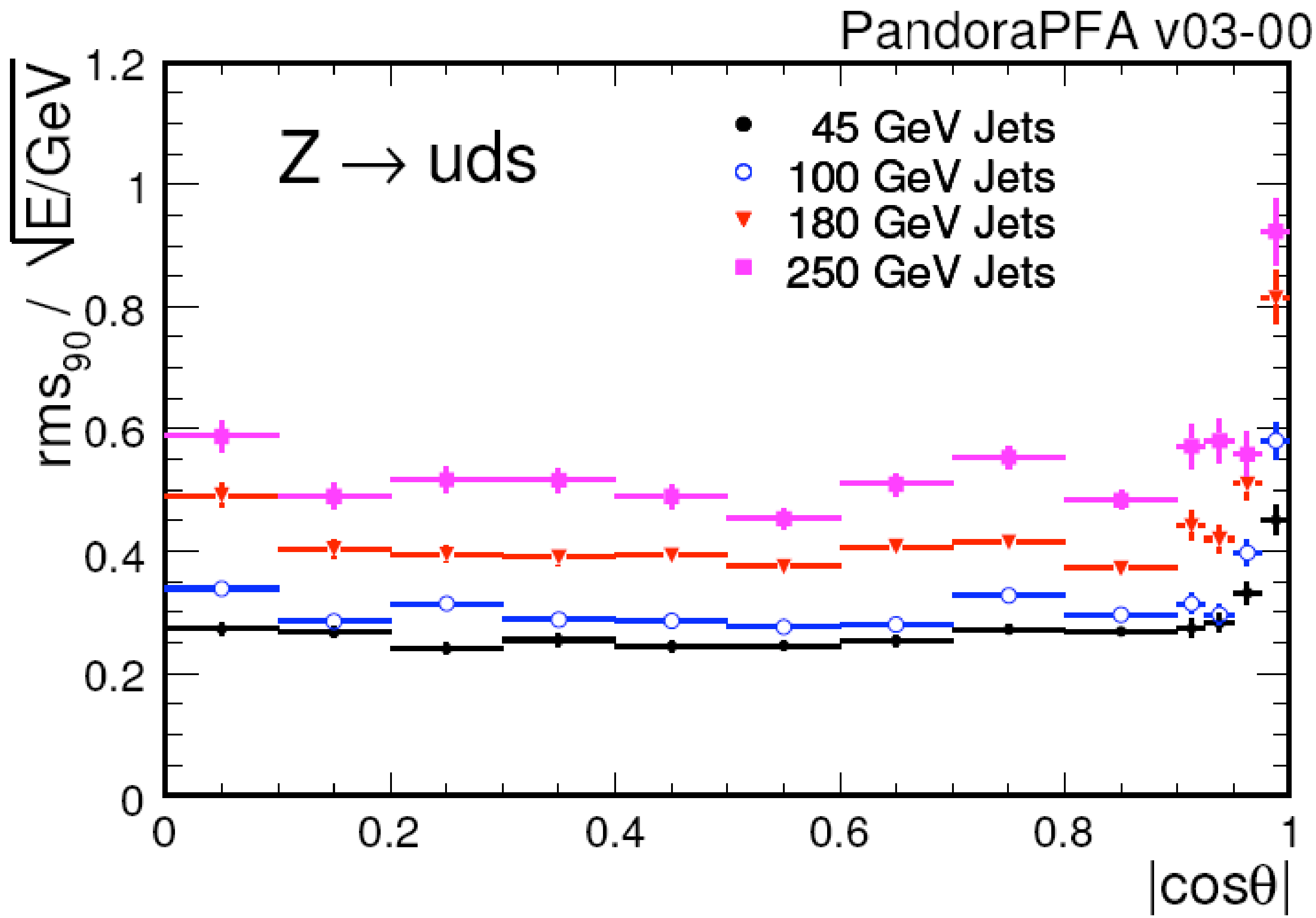
SiD LOI

Jet energy resolution
using Particle Flow Calorimetry



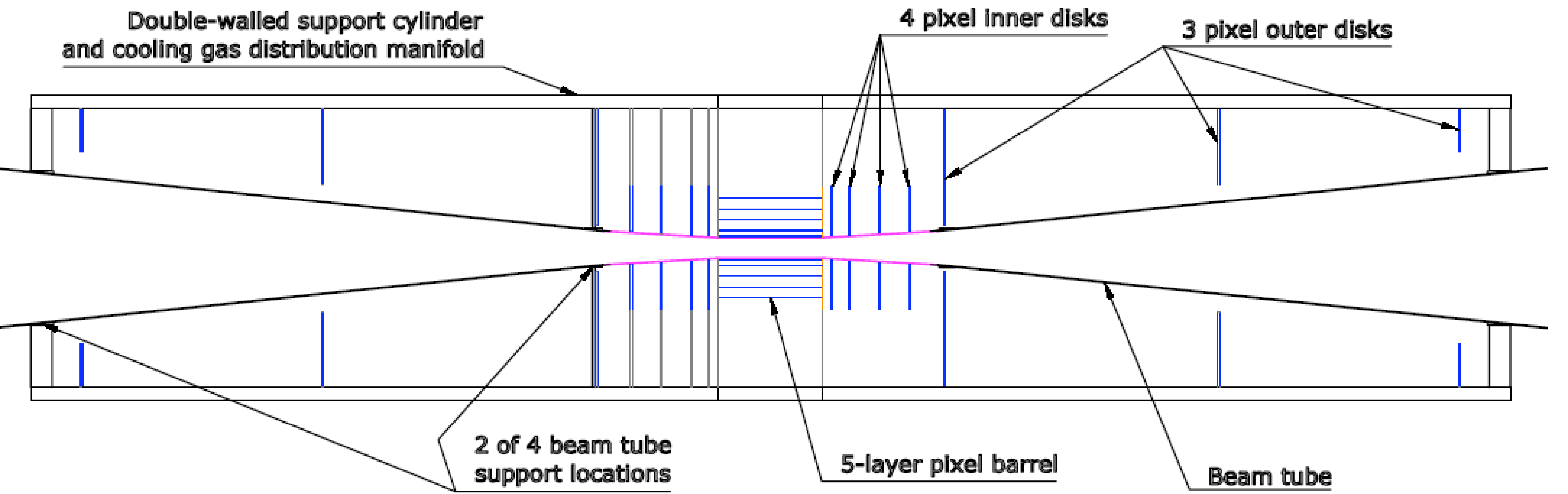
$\tau \to \nu\rho \to \nu\pi^+\pi^0$

SiD LOI



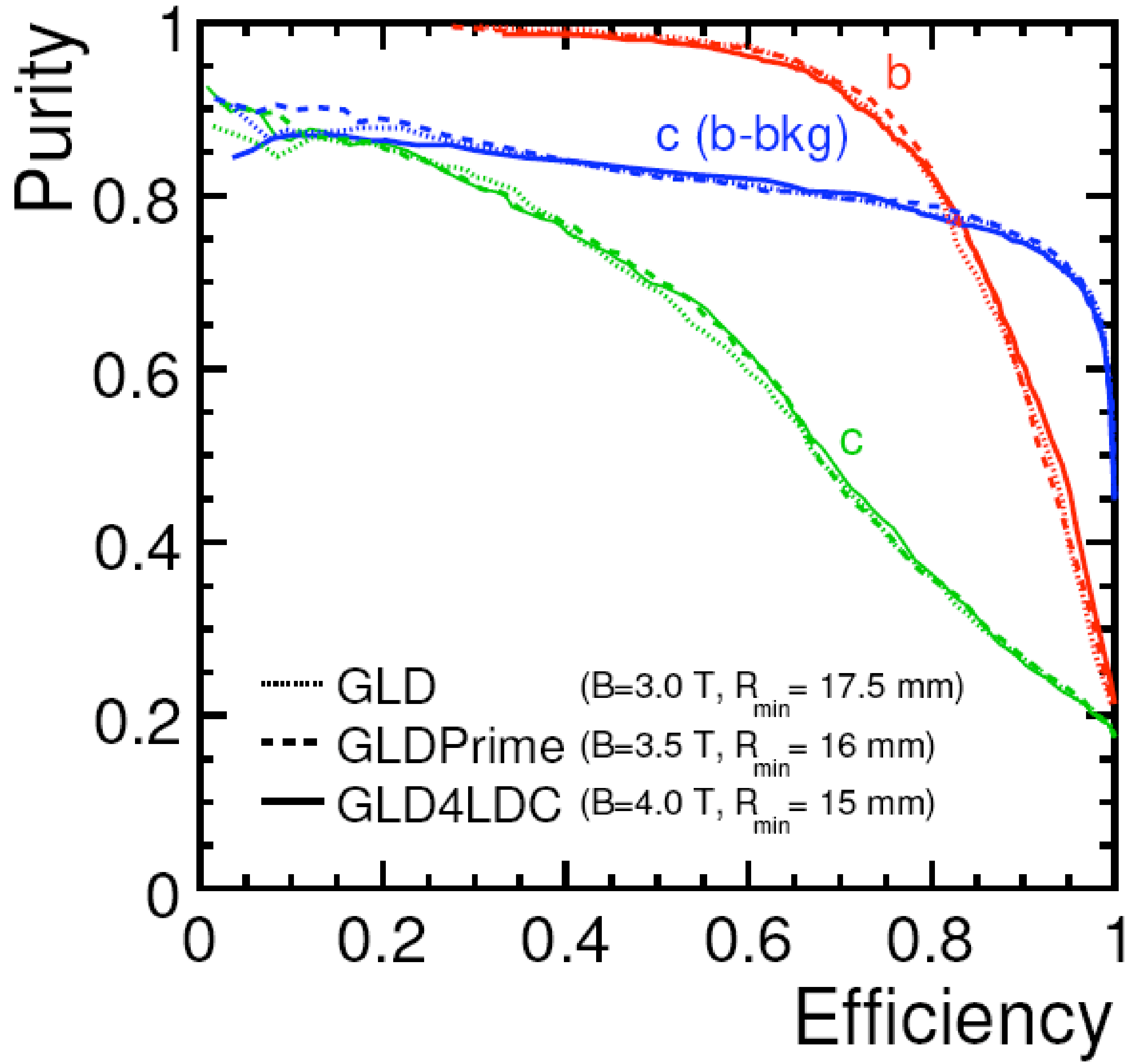
ILD LOI

vertex detector design: inner radius 1.4 cm



SiD LOI

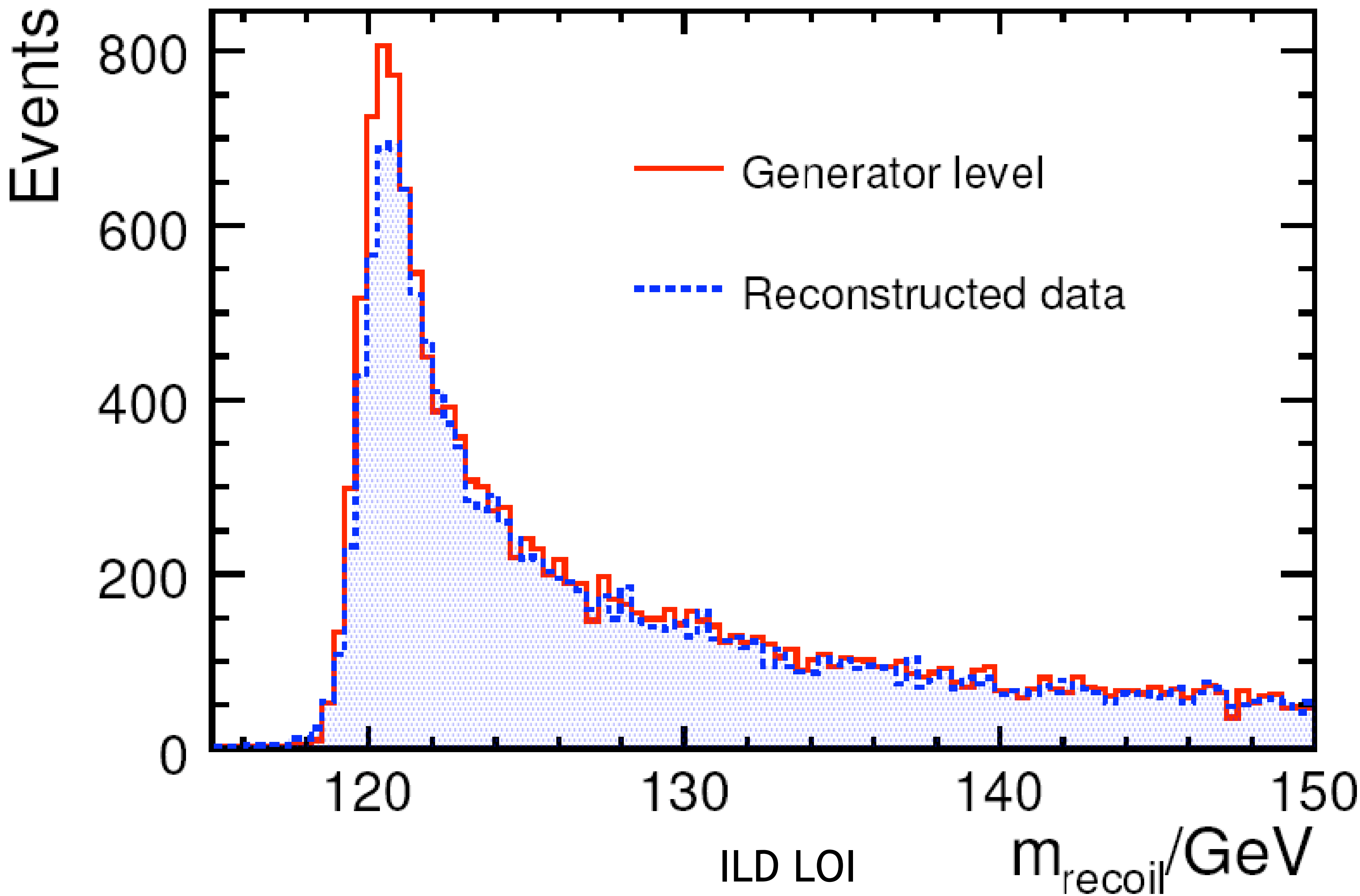
b, c tagging performance

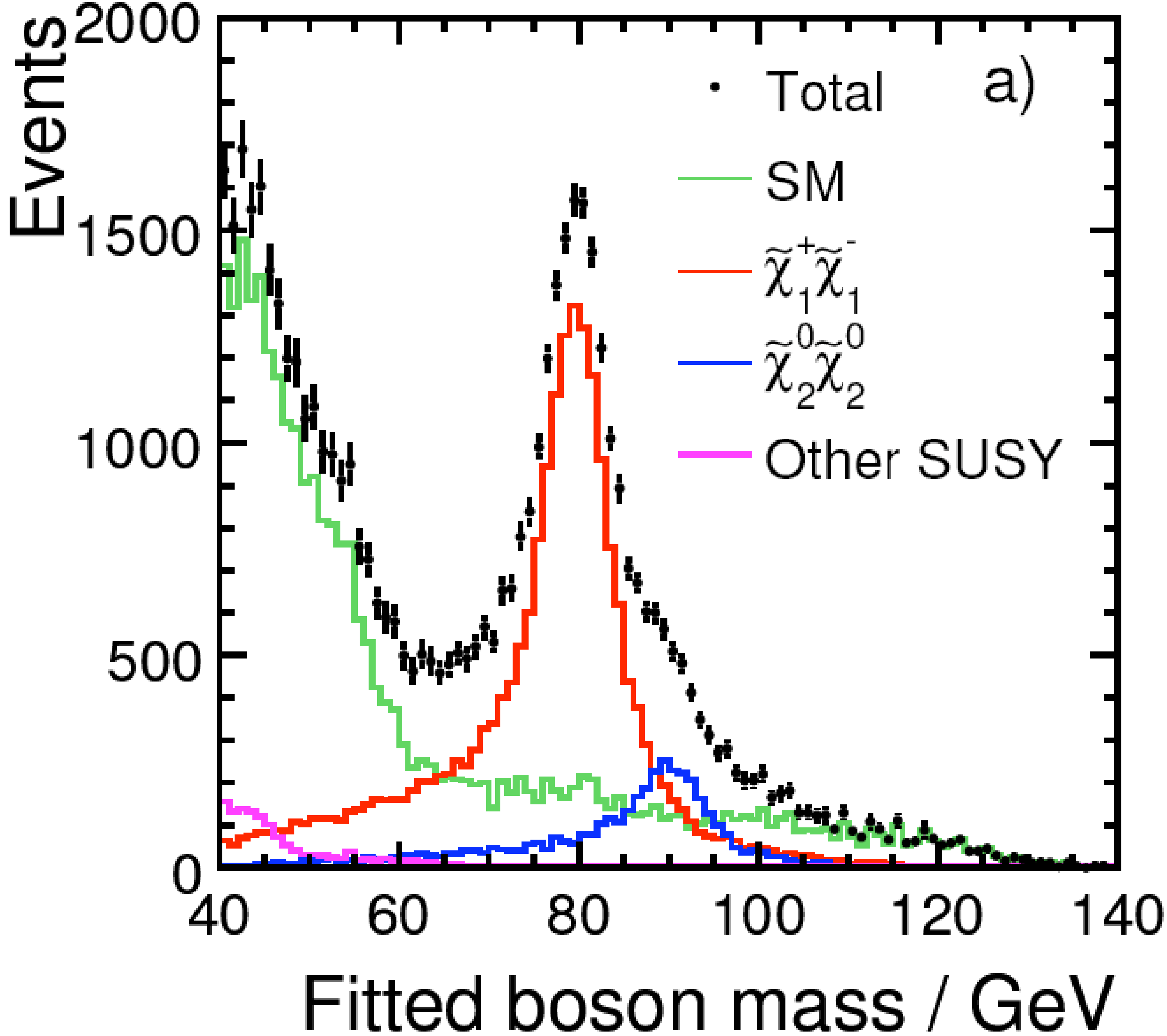


ILD LOI

Here are a few glimpses of the physics analyses in the LOIs:

Higgs recoil mass distribution

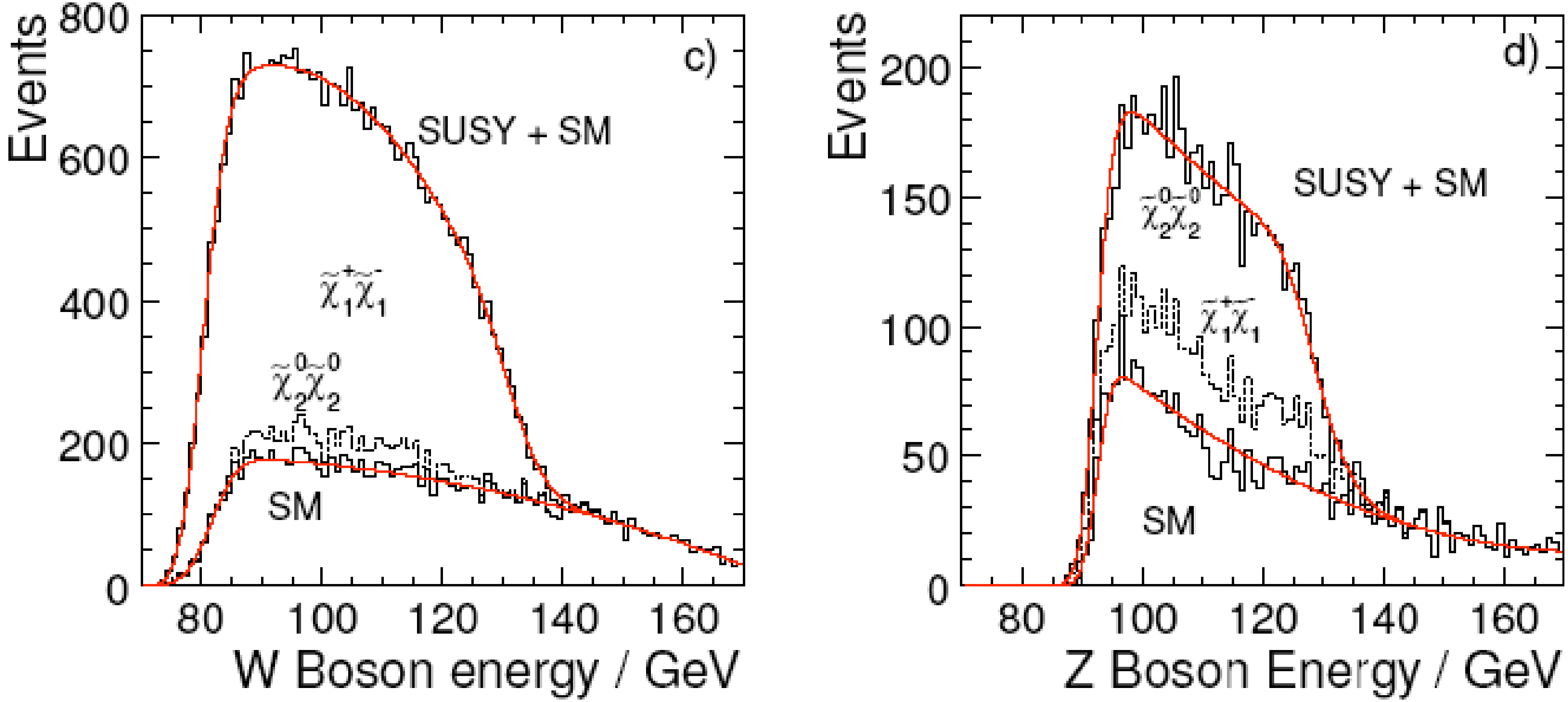




Events
2000
1500
1000
500
0
40
60
80
100
120
140
Fitted boson mass / GeV
Total
a)
SM
$\tilde{\chi}_1^+\tilde{\chi}_1^-$
$\tilde{\chi}_2^0\tilde{\chi}_2^0$
Other SUSY

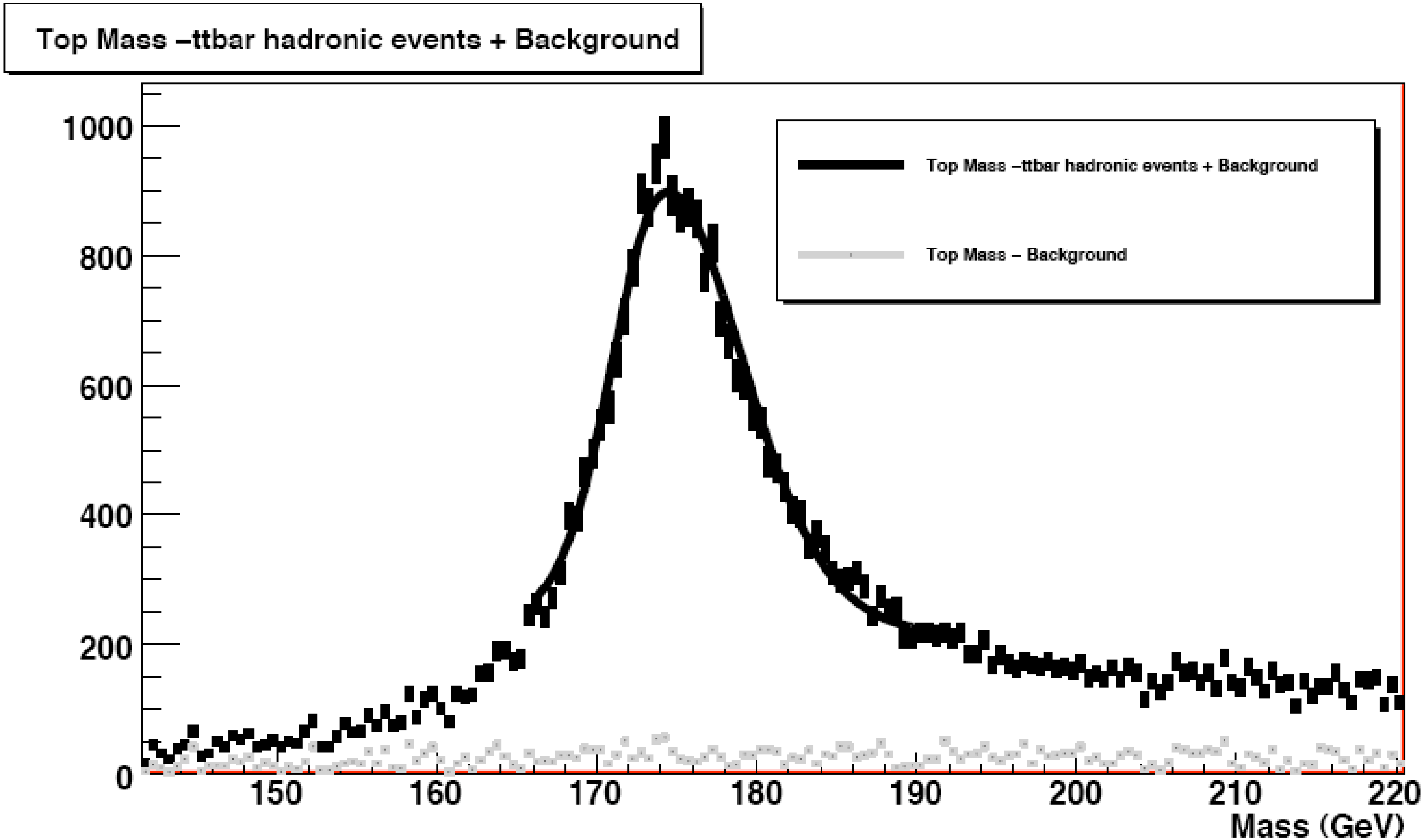
ILD
LOI

W and Z boson energy distributions in chargino/neutralino pair production



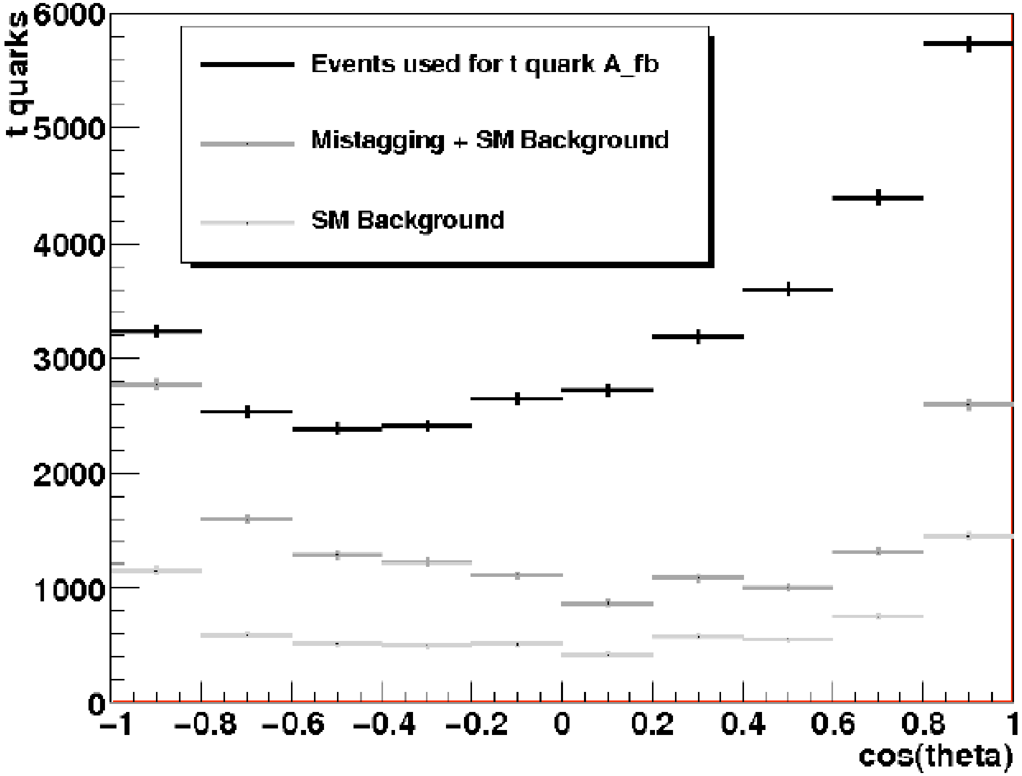
ILD LOI

top quark mass reconstruction at 500 GeV

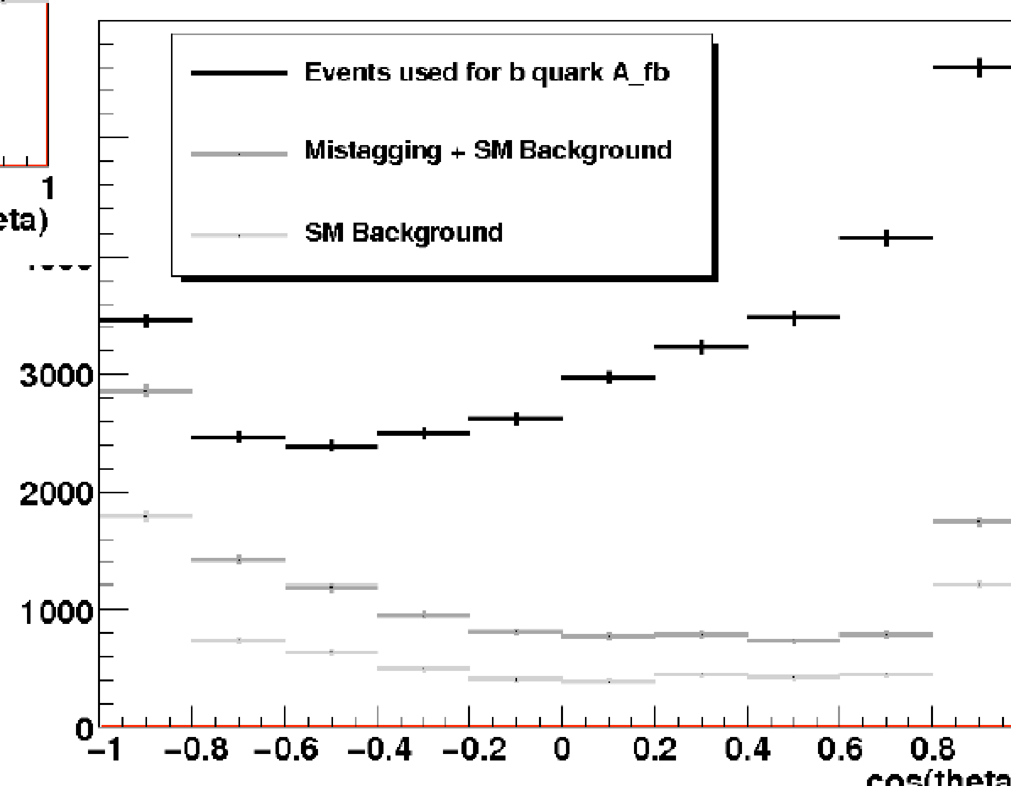


SiD LOI

angular distributions for asymmetries



t quark



b quark

Devetak and Nomerotski

What do theorists need to do to advance this program ?

-- specific calculational needs

-- thinking about future acceletators

For specific calculations, the major outstanding issues at the time of Loopfest I have been solved:

3-body electroweak processes at NLO, eg. $e^+e^- \to \nu\overline{\nu}h^0$

Belanger, Boudjema, Fujimoto, Ishikawa, Kaneko,
Kato, Shimizu (GRACE-LOOP)
Denner, Dittmaier, Roth, Weber

top quark threshold at 1% level:

Hoang, Manohar, Stewart, Teubner
NNNLO: Beneke, Kiyo, Schuller

$e^+e^- \to$ hadrons event shapes to NNLO

Gehrmann-de Ritter, Gehrmann, Glover, Heinrich
+ resummation: Becher and Schwartz, Abbate et al.

The most important outstanding issues are for simulation:

There is still no top threshold Monte Carlo that incorporates the best current theory. This is needed to make use of the full set of top threshold observables, in particular, the top quark pT distribution.

For new physics analyses, Standard Model multijet samples with up to 10 jets are needed. At the moment, WHIZARD can produce these at SM tree level process by process, but the number of processes grows rapidly with the number of jets. A better way is needed to construct complete background samples.

There is (unfortunately) no need to hurry to complete these projects.

Finally, I need to discuss the ‘urgency’ of the ILC. Since December 2007, the ILC has lost traction both in the US and in the world community.

The compelling physics arguments have not changed.   However, the cost of the ILC has become an important factor.

How do we think about the cost of the ILC ?

Earlier, I quoted a cost of $ 6.6 B. It is instructive to convert this to a DOE-type project cost for ILC construction in the US.

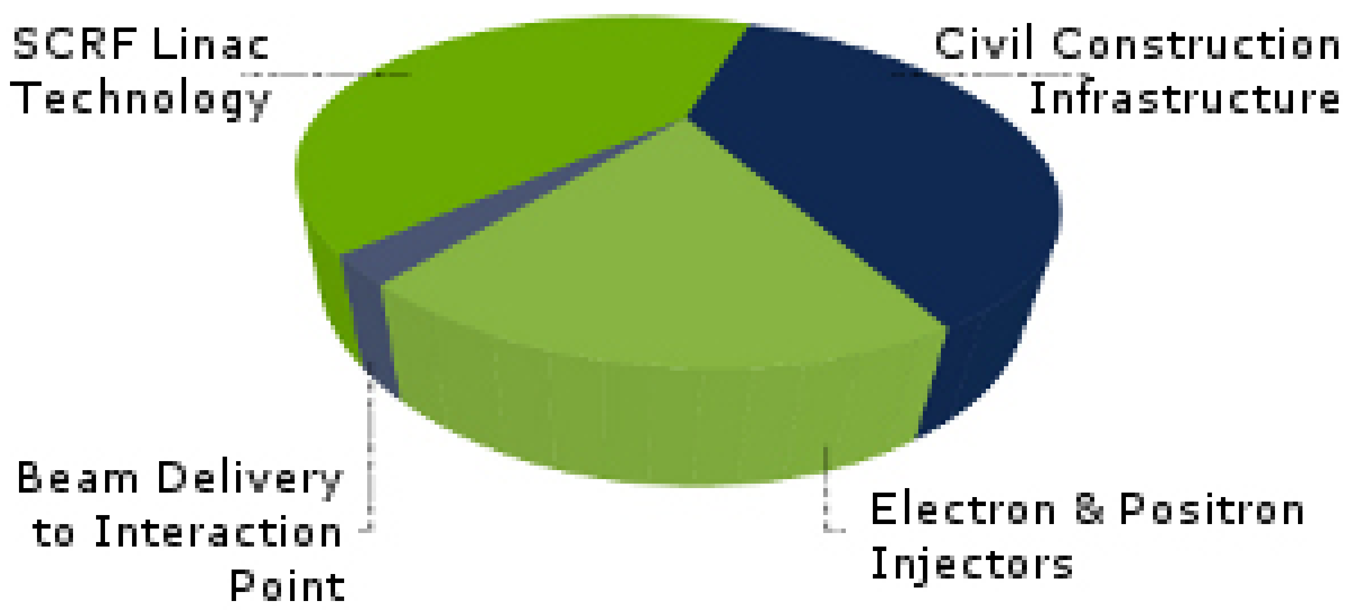
Straw-man schedule presented by Mike Harrison to P5 (2008)

US costing; FY 2007 dollars

Year	Funding Type	CD's	Funding $FY07	Funding at year	Inflator	Host 50%	non-Host 20%
FY11	Program	CD0	150	172	1.148	86	34
FY12	Program		250	297	1.188	148	59
FY13	PED	CD1	420	516	1.229	258	103
FY14	PED	CD2	795	1011	1.272	506	202
FY15	PED		1074	1414	1.317	707	283
FY16	Project	CD3	1492	2033	1.363	1017	407
FY17	Project		1900	2680	1.411	1340	536
FY18	Project		2174	3174	1.460	1587	635
FY19	Project		2300	3475	1.511	1738	695
FY20	Project		2200	3441	1.564	1720	688
FY21	Project		1700	2752	1.619	1376	550
FY22	Project		845	1416	1.675	708	283
FY23	Ops			0	1.734	0	0
	Totals ($M)		14900	21913		10957	4383
			Inflation	3.5%			

The host nation contributes $1B/yr in constant dollars.

There is no magic bullet for decreasing the cost of the ILC. The ILC will benefit from improvements in superconducting material manufacturing, but it is also a large civil construction project.   Here is the division of costs by subsystem:



Current revisions of the RDR will reduce costs by 6-8%, no more.

Other projects are being proposed that potentially compete with ILC.

CLIC, a 3 TeV e+e- collider based on two-beam acceleration, is being developed at CERN. The current design of CLIC makes strong use of X-band technology developed at SLAC and KEK, and those institutions are partners in the development.

A 3 TeV Muon Collider is now being studied at Fermilab. This facility would be a successor to Project X and a muon neutrino source at Fermilab; it requires those facilities as prerequisites.

These projects are still virtual. CLIC will be in R&D phase until 2020, the Muon Collider for much longer. The Muon Collider has very difficult machine-induced backgrounds that may prohibit precision experiments. The experimentation at these machines is just now beginning to be studied in a serious way.

Even if these projects are technically feasible and can be engineered, the choice among them is not clear:

These is no assurance that these facilities will be less expensive than the ILC.

Achieving very high energy might not be the most important issue. The key will be to understand the physics that we uncover at the LHC.

What is clear is that at most one of these facilities can be constructed.   We need to make the right choice, and to motivate it well.

The cost of the ILC is not prohibitive. The cost is comparable to that of LHC and ITER.

However, a project with such a cost must be organized globally. Its merits will be debated globally. They must be understood by citizens and politicians, not just by high-energy physicists.

The status of the LHC plays a crucial role here.

The technical failures of the LHC are a problem for any future high-energy physics project. LHC must be viewed by the public as a great success in order for ILC - or any other new accelerator - to go forward.

But there is more.

Members of the public do not understand why it is compelling to make precision studies of hypothetical particles.

To have the ILC, or any new accelerator, we must make discoveries at the LHC,

and it must be obvious to the public that these discoveries are among the most important recent results in all of science.

We know that physics is unending. The public asks to understand specifically what their dollars, euros, yen will achieve.

The participants in Loopfest must take these requirements seriously and ponder how they can be met. Otherwise, great discoveries can be possible, but we will not be able to make them.

the moral: 'Keep the faith, baby !'

For the LHC, these guys led a 25-year campaign.

Which of you will take us along the road to the next great machine ?